Laboratory Studies of Density Increase on Shelves

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LONG TERM GOALS

The long-term goal is to understand the fluid mechanics of buoyancy and wind driven transport on the continental shelf, including along-shelf transport and exchange with the deep Arctic Ocean.

OBJECTIVES

To understand flows in scaled laboratory experiments.

APPROACH

We developed prototype laboratory experiments and generated simple theories. The experiments and theories indicate design requirements for further experiments. We then design and conduct new laboratory experiments that yield important new observations of flow patterns and quantitative measurements of important parameters. These are compared with theory and ocean data.

ACCOMPLISHMENTS

In the six months since this program started, we have developed two simple theories and conducted one benchtop test. The first theory concerns the impact of density stratification of water on the sinking of dense water. We found that with simple algebra and box-models of a stratified ocean cooled from above, deep convection can suddenly switch on as cooling rate increases during the winter. Once convection is active, it will remain so as cooling declines in the spring. At a second lower value of the cooling rate, it will switch off. This contrasts with present numerical and theoretical models where the convection is simply proportional to cooling rate. The second theory has to do with the location of hydraulic jumps and the sites of mixing for density currents moving down a sloping bottom. A benchtop experiment tested the second theory. In both problems, a range of parameters is found with multiple equilibria—two distinct flows are possible for the same inputs. The figure shows two flows of water within this range. Water flows down a sloping channel from right to left and encounters a shoaling obstacle. The floor of the shoaling channel is a thin light line. The crest is underlain by a white crescent. In the top picture, the water has subcritical (deep) flow upstream of the obstacle. This subcritical flow is visible as the thick layer of water over the deepest part of the channel. Upstream of this subcritical layer is a hydraulic jump. In the bottom picture the water has supercritical (shallow) flow along the entire length. No hydraulic jump is present. This flow is typically found for greater angles. Because of multiple equilibrium, we can get from the first image to the second by first

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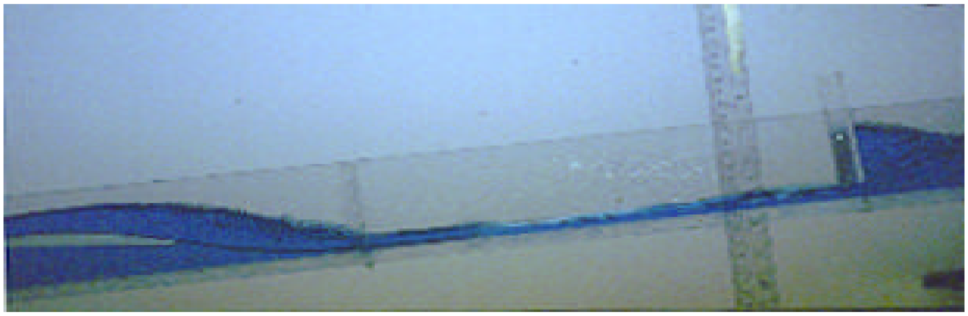
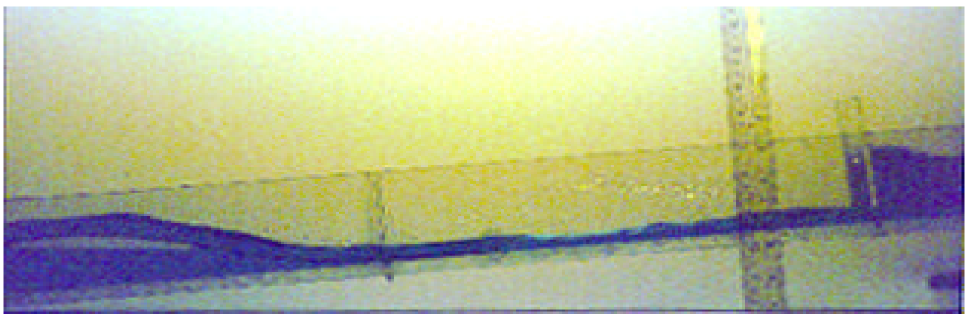
increasing the angle a little, thereby producing a transition to supercritical flow, and then decreasing it by a larger amount. Thus because of hysteresis the second can have a smaller angle than the first.





SCIENTIFIC/TECHNICAL RESULTS

The two simple theories both indicated that within a range of parameters, the strength of deep water formation and the location of mixing is sensitive to the history of how the processes is started. The intensity, magnitude, and the range of multiple equilibria is quantified with algebraic formulas. Thus scaled theory and benchtop experiments show that strength of deep water formation and the location of mixing is likely to display hysteresis.

IMPACT FOR SCIENCE OR SYSTEMS APPLICATIONS

The dependence of these processes on history means that oceanographers and numerical modelers must take this into account. Since the state can be history-dependent, steady numerical models will not have enough degrees of freedom to capture some of these effects. Regions with parameters favoring one state or the other would tend to have the ocean remain in that state. These experiments lay some foundation for more studies to be conducted in the next two years. The techniques we developed earlier (Whitehead et al. 1996) will be adapted to stratified fluid with topography of importance for the Arctic Ocean.

TRANSITIONS

In both problems we intend to describe these and related processes clearly in a manner accessible to oceanographers and students.

RELATED PROJECTS

In the first project, we intend to overlap with the work by Chapman and Gawarkiewicz. We are collaborating with Dr. Peter Baines of CSIRO, Aspendale, Australia on the second problem. He is an expert in such problems and has written a highly successful book on these processes in nonrotating flows.

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